Lateral Coherence and Mixing in the Coastal Ocean: Adaptive Sampling using Gliders

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LONG-TERM GOALS

Lateral mixing is driven through the interplay between finescale isopycnal stirring (shear + strain) and small-scale diapycnal turbulence. We seek to understand this interplay within highly anisotropic coherent structures, such as fronts, jets, eddies and filaments, which likely control lateral dispersion in both coastal and open ocean. These structures evolve yet are often persistent on O (3 day) timescales, so are ideally suited to be adaptively sampled by autonomous gliders that actively report both turbulent and finescale statistics.

OBJECTIVES

As part of a coordinated effort to quantify the meso- through micro-scale processes driving lateral dispersion, we plan to deploy 4 AUV gliders to perform intensive, adaptive surveys. Newly-enhanced to measure turbulent mixing, water-column currents and dye concentration, these OSU autonomous gliders will capture the interplay between shear, strain, and turbulence over a wide range of scales. In conjunction with ship-based dye release experiments, adaptive glider sampling will substantially increase the synoptic coverage of the dye surveys, providing a more complete description of the spread and dispersion of the dye. Microstructure sensors will allow for the quantification of small-scale mixing and its dynamical feedback to meso and sub-mesoscale flows. ADCP imaging of water-column velocity will (i) characterize the features driving fluid dispersion, (ii) help build better turbulence parameterizations in anisotropic environments, and (iii) will provide enhanced tracking capabilities for lateral coherence calculations. The scarcity of synoptic observations in the past has made it impossible to detangle the lateral and vertical processes. Adaptive sampling with multiple gliders in multiple locations for extended durations will provide the detailed statistics necessary for the community to make progress.

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APPROACH

We plan to deploy four newly-enhanced, autonomous gliders to measure the lateral coherence and evolution of dynamically significant properties. These properties include velocity (U), velocity shear (dU/dz), stratification (N2), temperature (T), salinity (S), temperature variance dissipation rate (χ), turbulence dissipation rate (ε), turbulence diffusivity (K_T), biological fluorescence, and, in cooperation with a dye release experiment, dye concentration.

OSU enhanced gliders are ideal sampling platforms for multiple reasons:

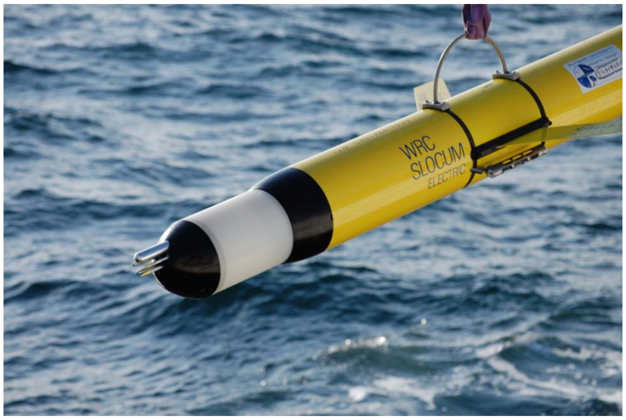
- Because they incorporate acoustic Doppler current profilers (ADCPs) with bottom-tracking capabilities, these gliders will be tracked while below the surface, permitting continuous spatial coherence computations on horizontal scales spanning O (10 m – 10 km). Gliders will also be equipped with a six component gyro package (3 linear and 3 rotational rate sensors) which will provide enhanced navigational capabilities at water depths where bottom-tracking is unavailable. All navigational data will be post-processed in a full LADCP-type inversion (i.e., Visbeck, 2002, Nash et al 2007) that utilizes all ADCP, gyro, and GPS data to provide both water-column velocity and vehicle location/speed.

- Because all data are logged and reported back on a regular basis, all data (including velocity and turbulence data) will be incorporated into the adaptive sampling that will be necessary to track laterally coherent features. This will be the first use of turbulence data for guidance of autonomous vehicles using adaptive sampling.

- Because each enhanced glider possesses measurement capabilities similar to that obtained during a single shipboard microstructure operation (albeit slower), a fleet of 4 enhanced gliders operating independently will both (1) sample more mixing/dispersion "events" from a statistical perspective, and (2) provide simultaneous observations at multiple locations – necessary for coherence calculations. The strength of this measurement is in addressing the interactions between isopycnal stirring via measurement of lateral coherence of dynamically significant aspects of the flow field and diapycnal mixing via direct turbulence measurements.

WORK COMPLETED

Tests were conducted in June 2009 (internal pod) over Stonewall Bank on Oregon's continental shelf with the two existing microstructure gliders. These were coordinated with Chameleon turbulence profiling.



Photograph of Webb glider with internal turbulence pod upon deployment in June 2009 over Stonewall Bank on Oregon's continental shelf.

We have ordered and taken delivery of two new Webb gliders, capable of diving to 350 m, outfitted with ADCPs and microstructure packages. The new gliders (John and June after John Allen and June Patullo) are being prepared for initial deployments in October 2010.

From 02 – 09 August, we conducted a pilot experiment on the R/V Cape Hatteras with groups from UMass Dartmouth, Woods Hole Oceanographic Institution and other Oregon State University scientists.

Ship departed 02 Aug 2010 at 0900 EDT. We were onsite in about 24 hours. During transit, set up access to ship's network and INFLO data being rsync'd by Daniel Birch. Deployed MVP and searched for feature to follow for Survey 1. 03 Aug 2010 at 1051 EDT at 74 45.0 W, 31 39.0 N found nice local max in flo-thru T about 10 km wide oriented along ~110°T, focused on northern edge with cold water north and warm water south, velocity transition from weak velocities north to about 40 cm/s to SW at 25 m depth south of front. We recovered MVP and deployed Acrobat. Surface mixed layer extends down to about 20 m; salinity well mixed but weak vertical temperature gradient.

Survey 1: 03 Aug 2010 1700 EDT to 04 Aug 2010 1500 EDT
We pumped dye from 1700 to 1800. Three drifters were deployed (at the beginning, middle and end); drifter ids 312646, 312910, 329215. We chose to follow middle drifter (312910) for glider doug's survey. Using central drifter deployment position and make_goto.m, we created a goto_l30.ma for doug and sent the ship to the second waypoint for deployment. Doug's survey was oriented along 110°T. On site (74 38.43 W, 31 35.26 N) with doug at 1817 EDT, run status.mi on deck, deploy in 'normal' fashion from starboard side rail cut-out (slide doug into water off cart, use pole to keep doug from hitting side of ship), run status.mi in water. Cannot dockzr while freewave is connected!

We started doug on hourly call-ins and then switched to 3 hours around 2200 EDT. We developed a routine for updating doug's goto_l30.ma file (waiting for upload on dockserver); ftp log files, copy drifter position file, glider_underway.m (makes goto_l30.ma file using latest drifter positions and plots drifter/glider positions), ftp goto_l30.ma to dockserver. Lost satellite internet connection during the night, ship's tech had to restart router. West heading also corresponds to bad internet connection. On 04 Aug 2010 at 1332 EDT, we recovered glider doug from starboard rail cut out (same as where we deployed), using our hook and pole, broom on pole to fend off glider, small ship's block, hand winch and line (mounted on ship's rail).

The drifters headed SW then turned and headed W at 40 cm/s. Glider flew a southward trajectory then turned west (Figure 1). The drifter relative track passed right over the drifter (Figure 2). In 15 hours, glider doug flew approximately 1.5 lines. Average vertical profiles of temperature, salinity, density and N^2 show weak stratification in the upper 20 m with salinity reaching a minimum at 20 m, and peak stratification at 30 m (Figure 3). Salinity reaches a maximum at 40 m. T-S plot of glider observations reveal a strong dive-climb hysteresis (Figure 4). There is very little horizontal variation in temperature, salinity or density (Figure 5).

Survey 2
After recovery, preparation for Survey 2 began immediately. We drove around using flo-thru and ADCP at 25 m to identify the next feature. On 04 Aug 2010 at 1647 EDT at about 74 54.905 W, 31 54.493N, we found a front with cool water to the north flowing southward at 35 cm/s into warm water to the south with weak westward flow (or no flow at all). We thought this might be a likely candidate for subduction.

After dinner we deployed dye for 1.5 hours. The dye was laid out on a roughly east west line. Four drifters were deployed. We followed drifter 329215. Doug's survey was oriented NS. We deployed doug at 2053 EDT at 74 55.440 W, 31 52.529 N. We deployed doug using the small quick release hook. We did one 1 hr dive, and then started 3 hr dives. We stream lined the update process by reading the drifter data file directly from the shared drive (no more copying). Also, discovered matlab has an ftp utility!

The drifters headed south, veered SW, then W (Figure 6). doug flew with out interruptions for 36 hours, maintaining the line relative to the drifter (Figure 7). We had trouble with 'Hit a Waypoint' triggering early (>1 km away), yielding some short sections in drifter space. We solved this by extending the lines. We also tried referencing the glider flight to a predicted drifter position 1.5 hours into the future. This produced poor results, steering too far east in drifter space (Figure 7). Over all, our ability to fly a coherent pattern improved, we completed 5 sections (about 7-8 hours per).

We lost internet during 06 Aug 2010 1030 EDT call in. Once re-established, we checked dockserver and determined doug had called in on time, but dropped the call while rereading ma-files and didn't call back. doug did not call in as scheduled at 1330 EDT. doug called in as scheduled at 1629 EDT. doug was very close by, so we recovered at 1708 EDT 06 Aug 2010. Because doug missed a call in, no updated goto_l30.ma file was uploaded and the glider lost position in drifter space. This suggests six hour call ins are too long – three hour may be optimal.

Average profiles looked similar to Survey 1, although the surface layers was more well-mixed – very weak vertical temperature gradient and salinity minimum barely identifiable (Figure 8). TS properties were unchanged (Figure 9). Hydrography reveal very little variation, except possibly near day 217.7 when there is a feature that could possibly be a front (Figure 10).

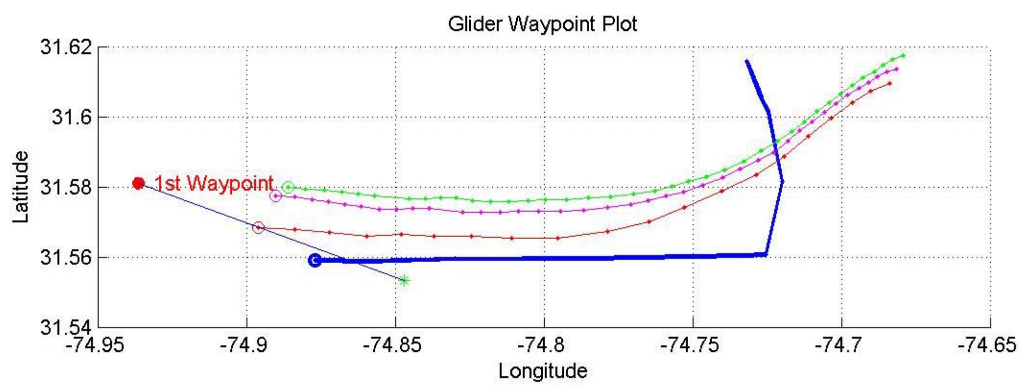


Figure 1: Drifter and glider (thick blue line) trajectories for Dye Survey 1.

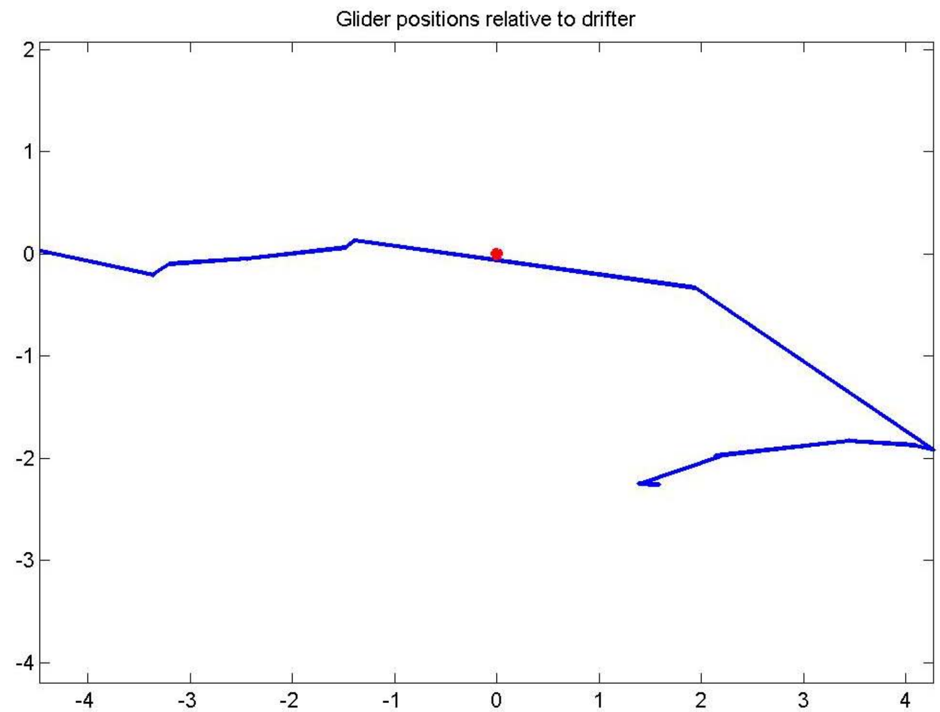


Figure 2: Glider trajectory in drifter space for Dye Survey 1

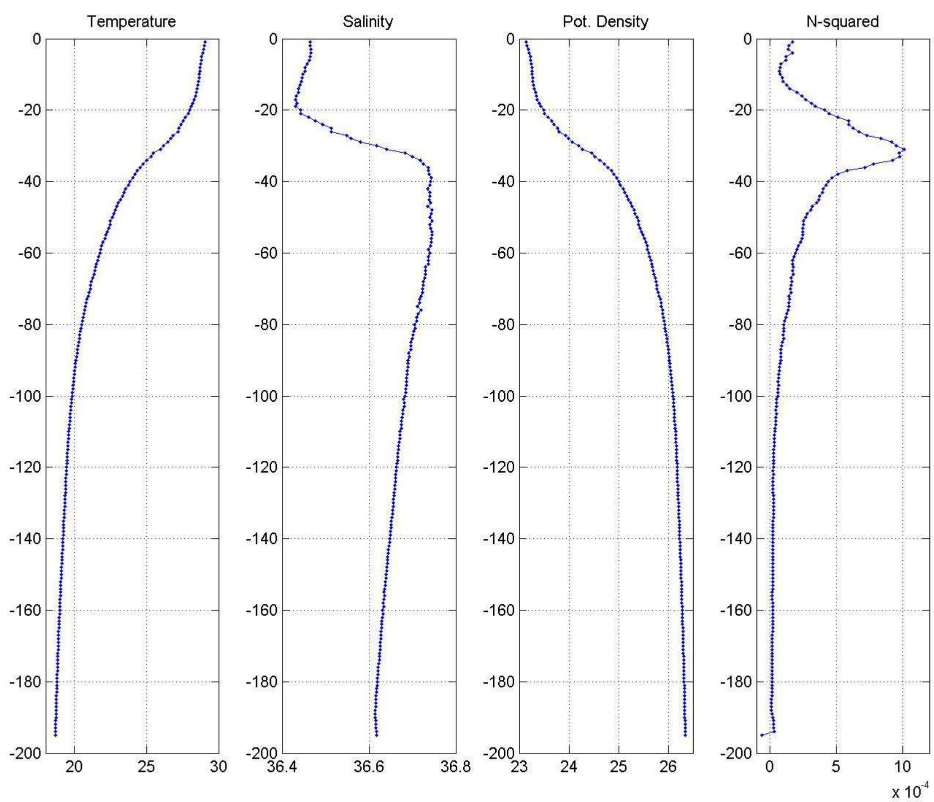


Figure 3: Average vertical profiles of (from left to right) temperature, salinity, density and N^2 for Dye Survey 1.

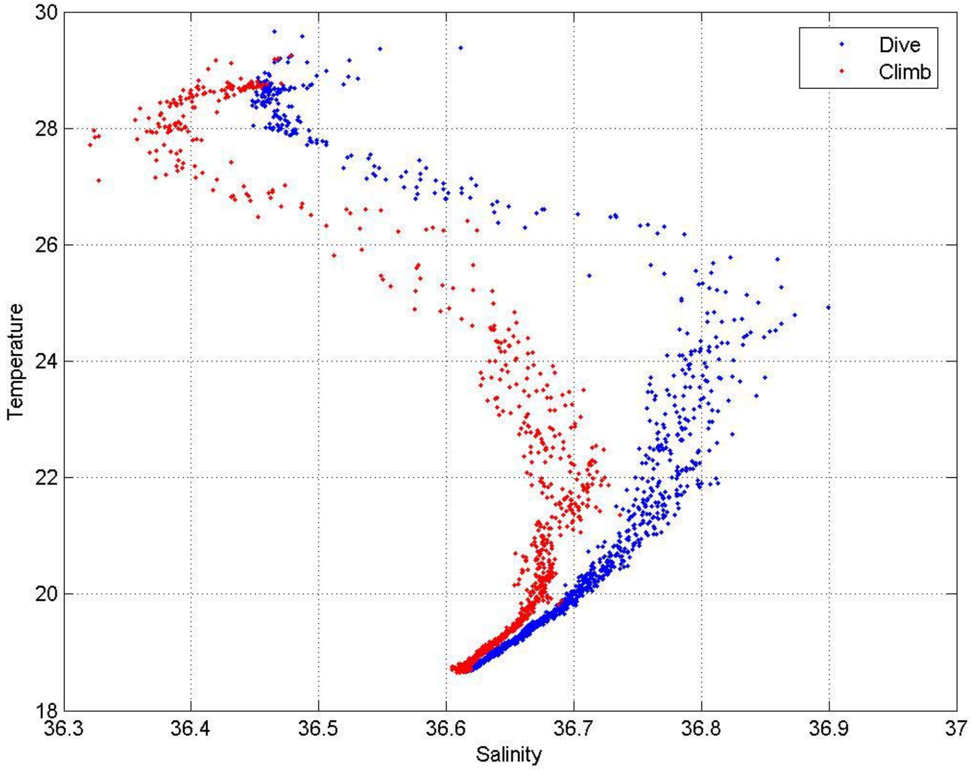


Figure 4: Temperature versus salinity for Dye Survey 1. Upcasts (climbing) are colored red and downcasts (diving) are colored blue.

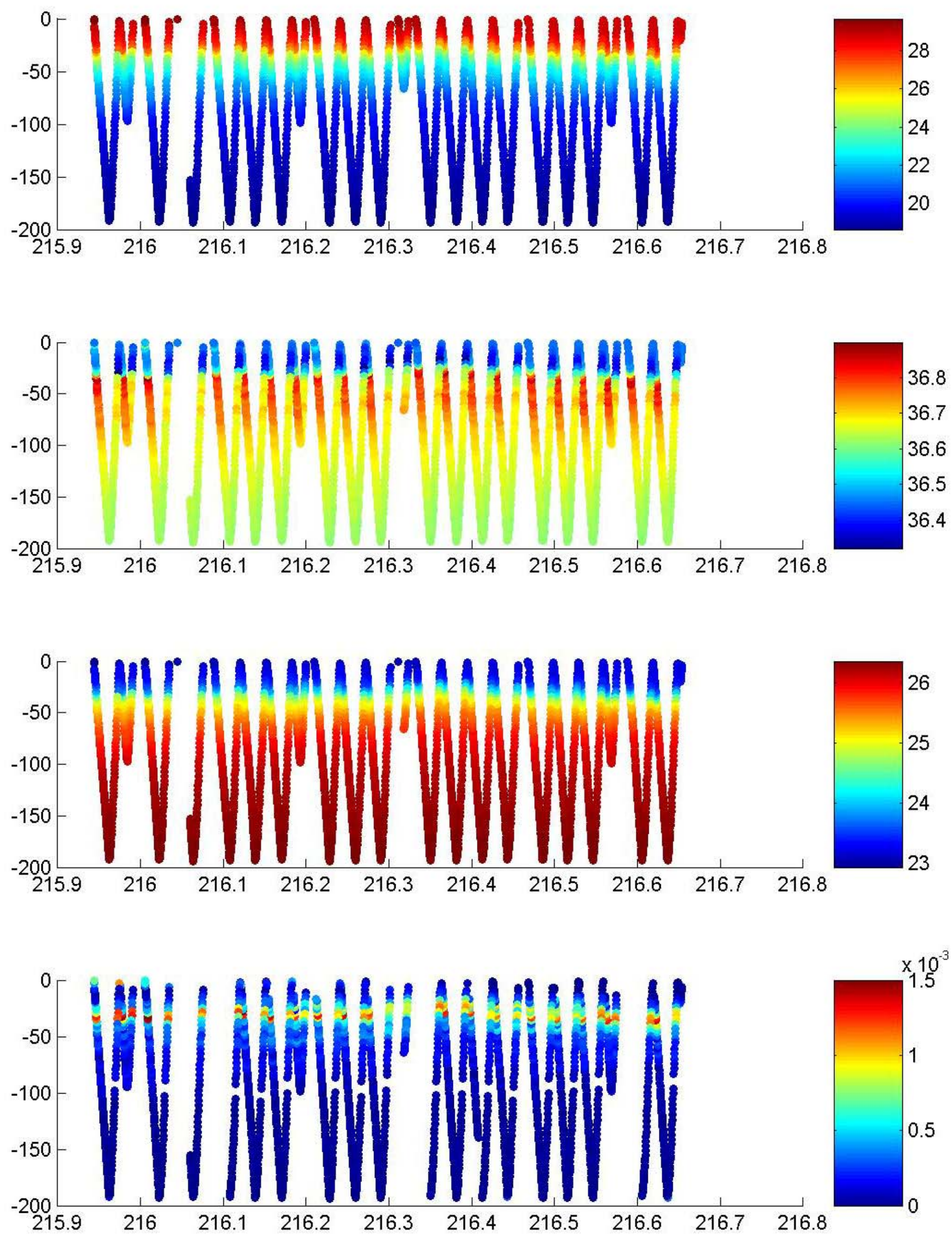


Figure 5: Vertical section of (from top to bottom) temperature, salinity, density and N^2 for Suvey 1.

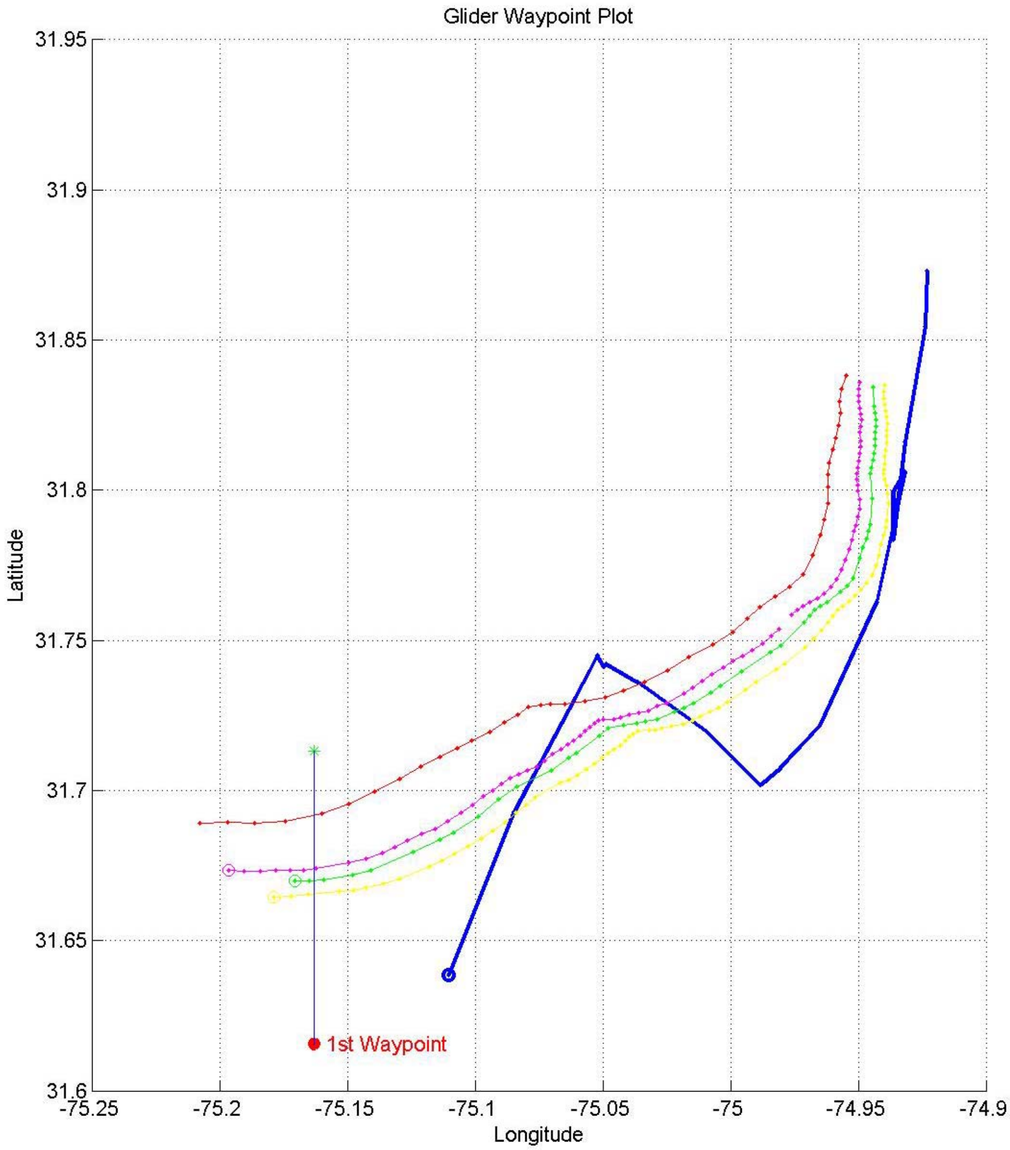


Figure 6: Drifter and glider (thick blue line) trajectories for Dye Survey 2.

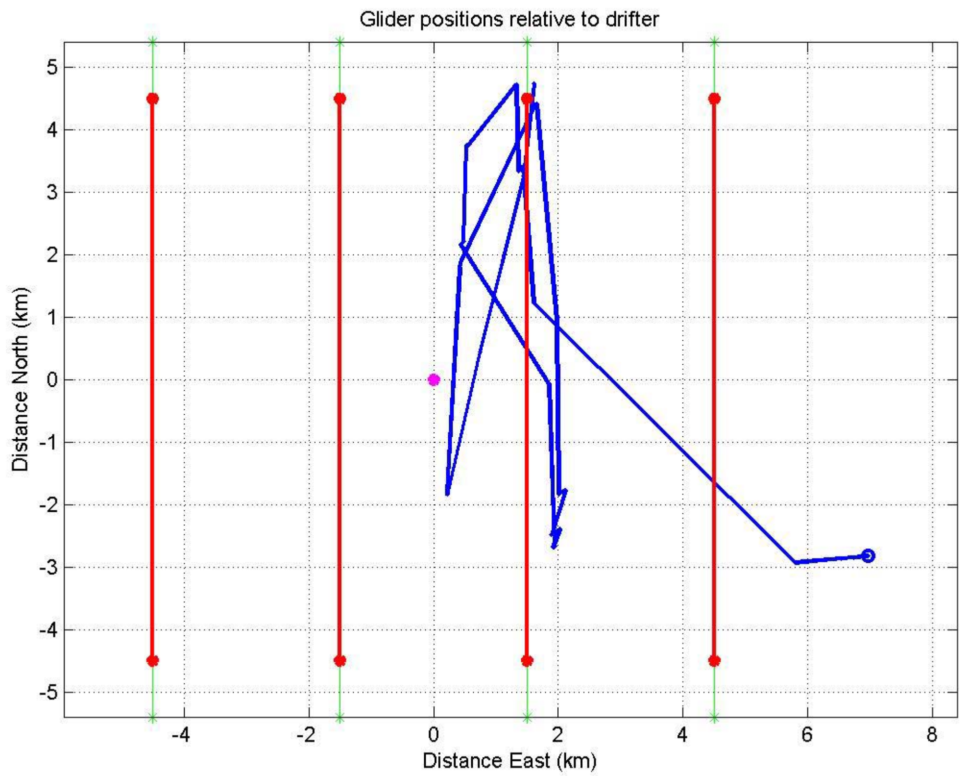


Figure 7: Glider trajectory in drifter space for Dye Survey 2.

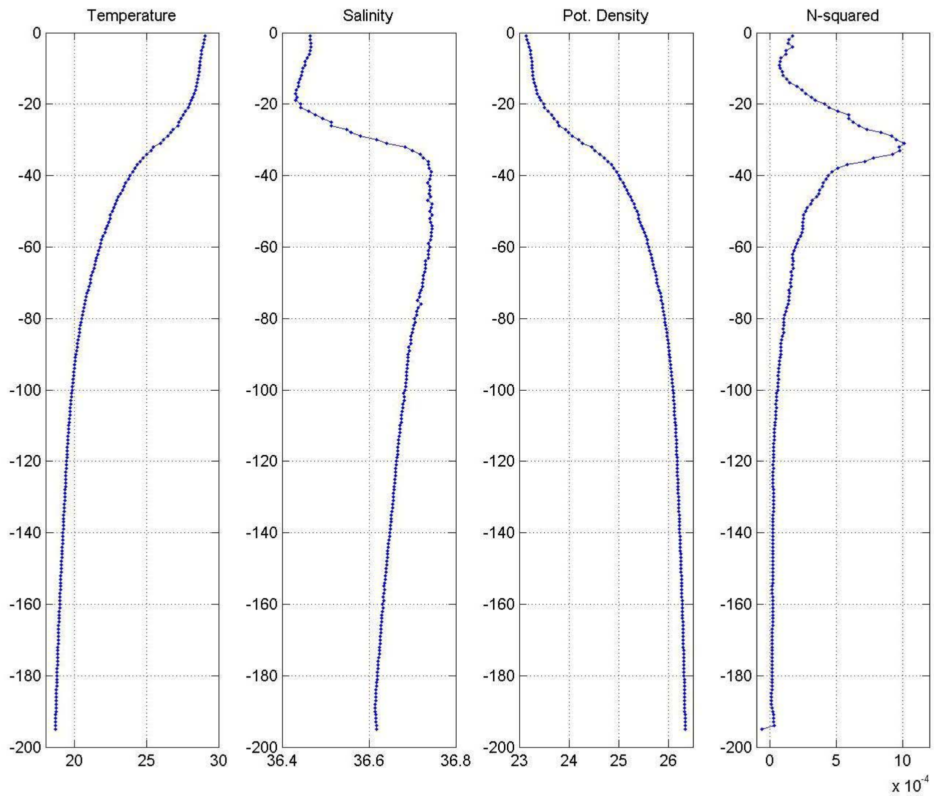


Figure 8: Average vertical profiles of (from left to right) temperature, salinity, density and N^2 for Dye Survey 2.

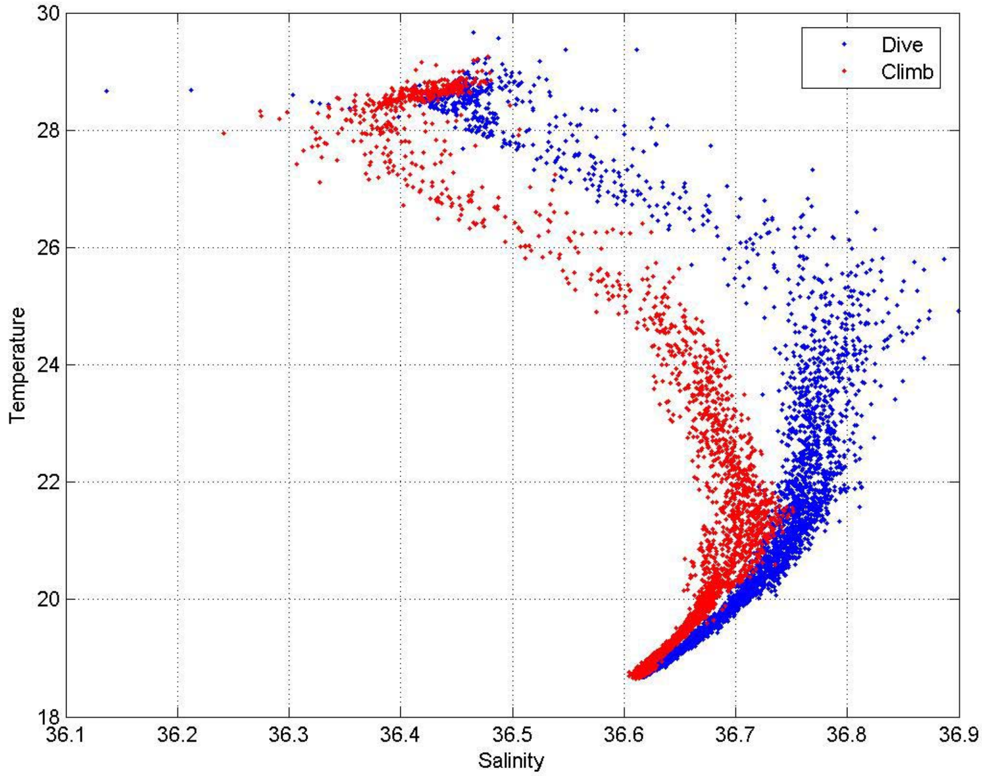


Figure 9: Temperature versus salinity for Dye Survey 2. Upcasts (climbing) are colored red and downcasts (diving) are colored blue.

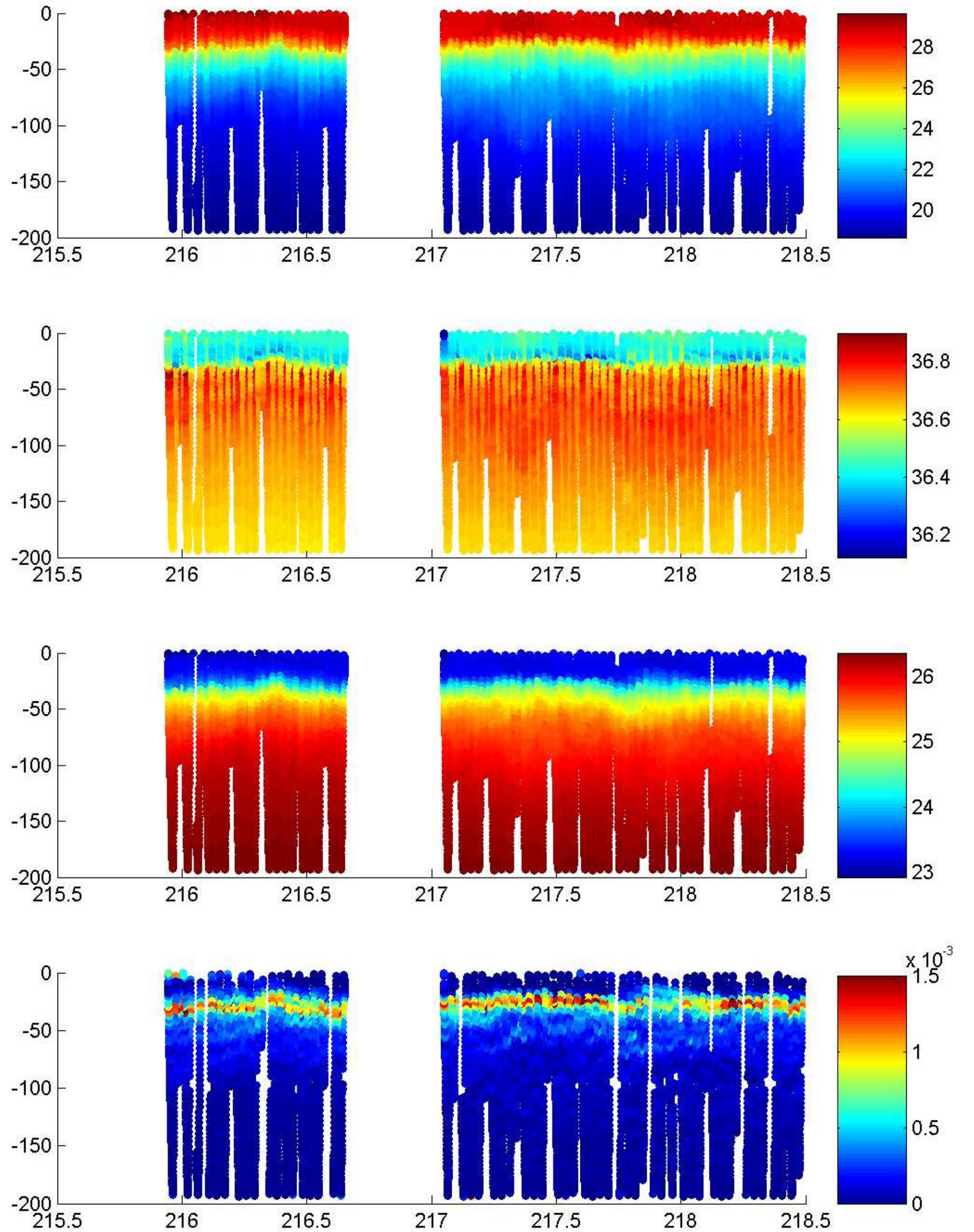


Figure 10: Vertical section of (from top to bottom) temperature, salinity, density and N^2 for Suvey 2, beginning on day 217 and ending on day 218 (glider doug recovered).

RESULTS

The success of the gliders at flying a survey pattern relative to a moving drifter confirms our strategy for the main field experiment in June 2011.

IMPACT/APPLICATIONS

Gliders offer a means of making two very valuable types of relatively autonomous measurements in the ocean. The first is the type of repeated routine observation that permits establishment of a climatology from which significant deviations can be identified and addressed. The second is the observation of extreme events (such as hurricanes) that cannot be made from ships. We have established standards of ocean turbulence measurements and have extended our ship-based vertical and horizontal profiling packages to moored mixing measurements. It has been a natural evolution to use this expertise to integrate new sensors into gliders that will both begin to define climatologies of mixing in coastal waters and lead to turbulence measurements in events such as hurricanes for which we have limited or no observation.

PUBLICATIONS

Wiles, P.J., J.N. Moum, S. Glenn, K. Shearman and J.D. Nash, 2009. Glider observations of pycnocline mixing over the Mid-Atlantic Bight induced by Tropical Storm Hanna, in draft form for *Geophys. Res. Lett.*